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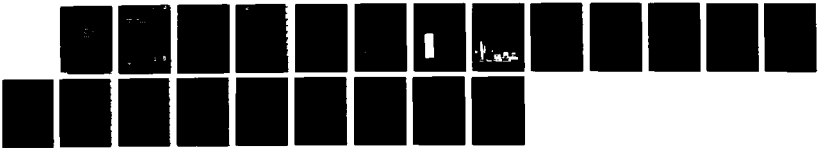

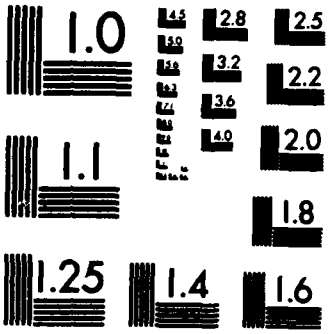

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A SEMIAUTOMATED SYSTEM FOR MOIRÉ STRAIN ANALYSIS

ALAN H. KATZ

MECHANICS AND STRUCTURES DIVISION

March 1987

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ABSTRACT

A method for analyzing Moiré fringe photographs without acquiring point by point data manually is described.

A computer controlled video digitizer is used to acquire video intensity data for up to 1024 x 1024 pixels per photograph. Software was developed to acquire the data and store it locally to the digitizer's computer.

Data reduction and analysis is performed on a host minicomputer. Software for this host was developed to upload all the data, perform error checking and subsequently perform the reduction and analysis.

The data analysis is performed using a finite element global smoothing technique. This method allows the displacements to be input to the analysis and the strains determined.

Results may be plotted as contours of strain or slices may be taken at any location in any direction.

Keywords: Strain (mechanics); Image processing; Computer applications; Fourier analysis; Computer programming.

CONTENTS

	Page
INTRODUCTION	1
DATA ACQUISITION AND ANALYSIS	1
DIGITIZING FRINGE PATTERNS	2
ERROR CHECKING	3
DATA PROCESSING	3
DETERMINATION OF FRINGE CENTERLINES	5
IDENTIFICATION OF MOIRÉ FRINGES	6
STRAIN DETERMINATION	6
CONCLUSIONS	9
ACKNOWLEDGMENTS	9
BIBLIOGRAPHY	11

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INTRODUCTION

Moiré measurement techniques are being used at MTL for the analysis of strain in test specimens. Acquisition of data from the Moiré fringe photographs has been performed manually in the past, and has been tedious and of limited precision. This work is an effort to improve both factors and also to allow more widespread use of Moiré strain analysis in this laboratory.

The focus of the work is in two primary areas. First is the development of software for the MTL video digitizing system which consists of a Hamamatsu C1000 video digitizer and a Hewlett-Packard 9845B desktop computer which controls the digitizer and acquires the data. Second is the software for a mainframe type computer which would reduce the data, perform all the anlysis, and provide graphic output in the form of contours or profiles of strain.

DATA ACQUISITION AND ANALYSIS

A typical Moiré fringe photograph is shown in Figure 1. The spacing between two adjacent fringes represents a displacement increment which is equivalent to the pitch of the gratings utilized in forming the fringe pattern. The example is shown schematically in Figure 2. It is a flat composite-material specimen which is pin-loaded vertically upward with the lower end clamped.

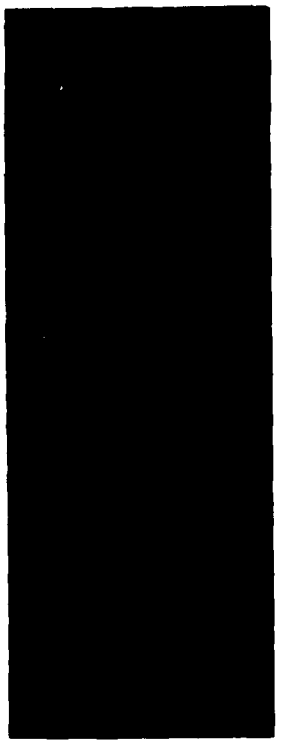

Figure 1. Typical Moiré fringe photograph.

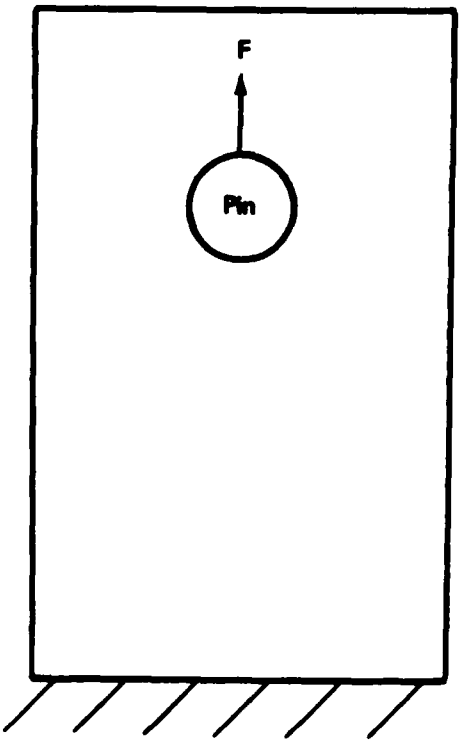

Figure 2. Schematic example of loaded composite specimen.

The object of the work is to:

1. Digitize the fringe patterns.
2. Filter out the noise which is present.
3. Locate the centerlines of the fringes.
4. Identify groups of points as belonging to the same fringe.
5. Assign fringe orders to the groups of data.
6. Create a mesh for the case under study.
7. Use finite element technique to smooth data and provide strains over the field.
8. Produce desired plots.

DIGITIZING FRINGE PATTERNS

The MTL video digitizing system, shown in Figure 3, is used for digitizing the fringe patterns and storing the data in computer mass storage. The system is shown in Figure 4.

The system is capable of digitizing a field into an array of video intensities (values 0 to 255, 8 bits) which is 1024 x 1024 pixels. The resolution obtained is determined by the magnification produced by the optics of the digitizer camera.

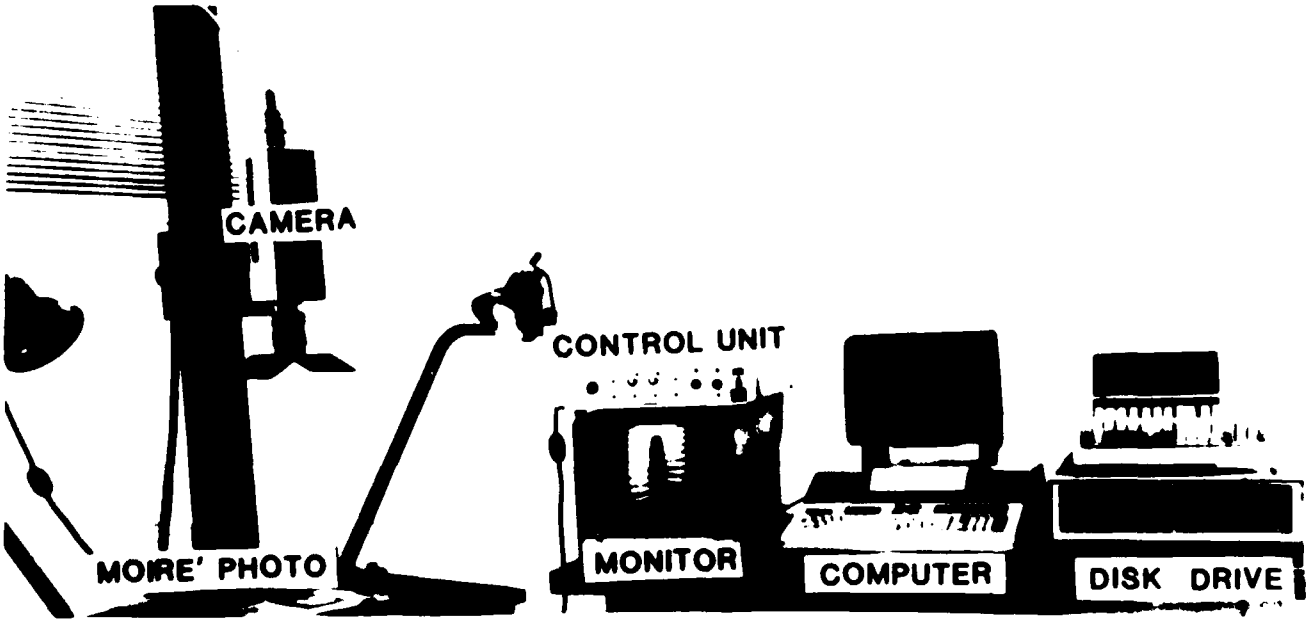

Figure 3. MTL video digitizing system.

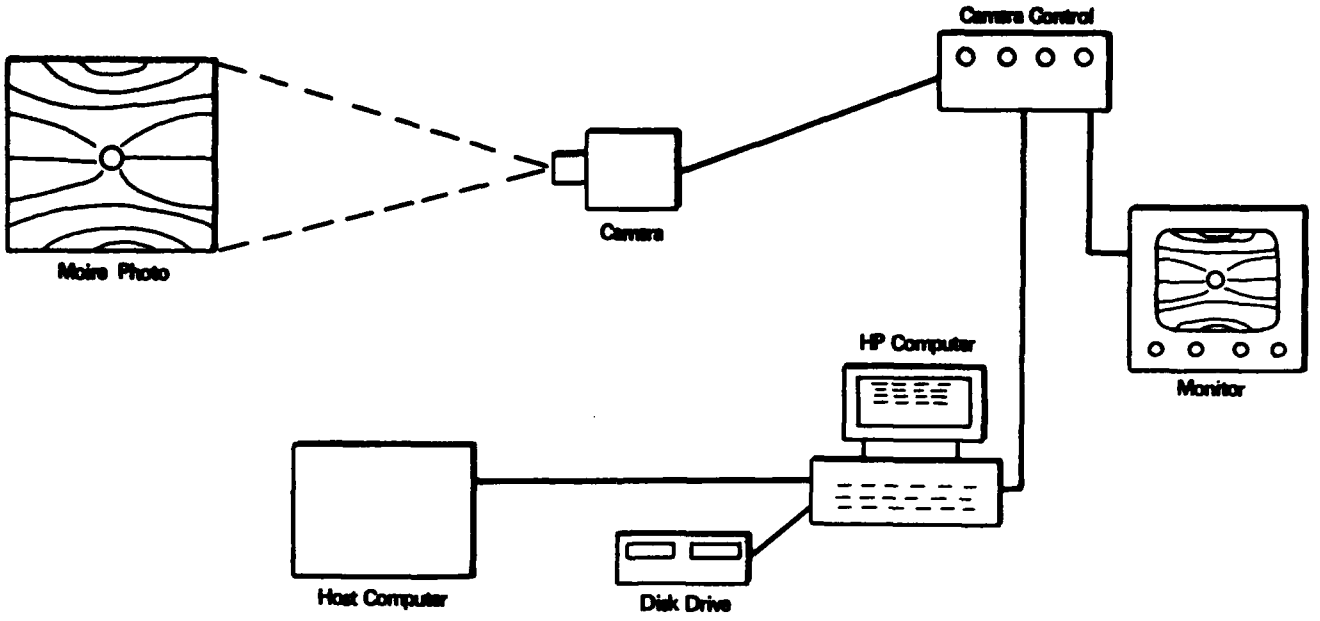

Figure 4. Block diagram of digitizing system.

For many of the cases of interest to this laboratory, it is unnecessary to use the full capability (1024 x 1024) of the system. This reduces the time necessary to digitize a field and also the time required to transmit the data by telephone to the host computer for processsing.

Due to the slow speed of the 9845B and the large amounts of data to be processed, no preprocessing is done by it. All of the data are sent to the host by telephone and processing performed subsequently.

ERROR CHECKING

The data which are sent to the host computer are in the form of octal digits. When they are uploaded, due to the limitations in the uploading program, they are sent in blocks which cannot exceed 64,000 characters. After each block is received, it is checked for transmission errors and, if none are found, it is written out to disk. If an error is found, the process is repeated again until there are no errors.

The errors checked for are nonoctal digits, nonnumeric characters, and spaces that should not be there.

DATA PROCESSING

All data must be decoded before any further processing can be accomplished. Due to interlacing of the video digitizer image, the data are not in the same order as the pixels on the video screen. Each octal number contains the video intensities of two nonadjacent pixels. These octal numbers must be separated and then placed in their proper sequence, as they appear on a vertical line on the video screen.

After decoding, the data are filtered by the use of Fast Fourier Transform (FFT) and an exponential low pass filter transfer function.[1] This removes many of the high frequency components.

A plot of video intensity along a scan is shown in Figure 5. (This scan is located at the vertical line shown in Figure 6.) The top curve is the unfiltered data. The bottom curve is the same data after filtering. The reduced amplitude after filtering does not influence the results because only the locations of the fringe centerlines are used and not the intensity values.

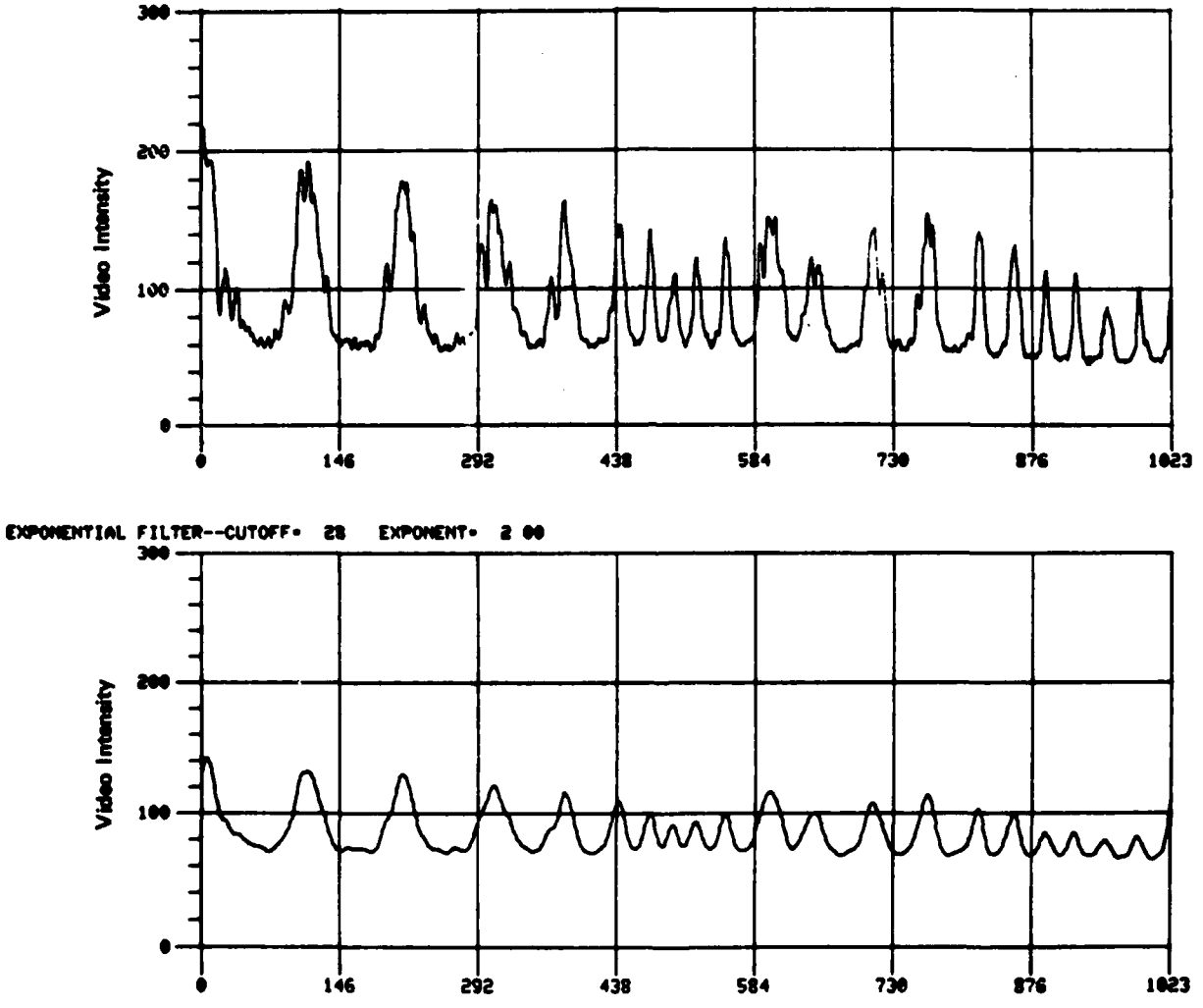

Figure 5. Top - raw video intensity data along one scan
bottom - same data after filtering.

1. GONZALEZ, R. C., and WINTZ, P. *Digital Image Processing.* Addison Wesley Publishing Co., Reading, MA 1977.

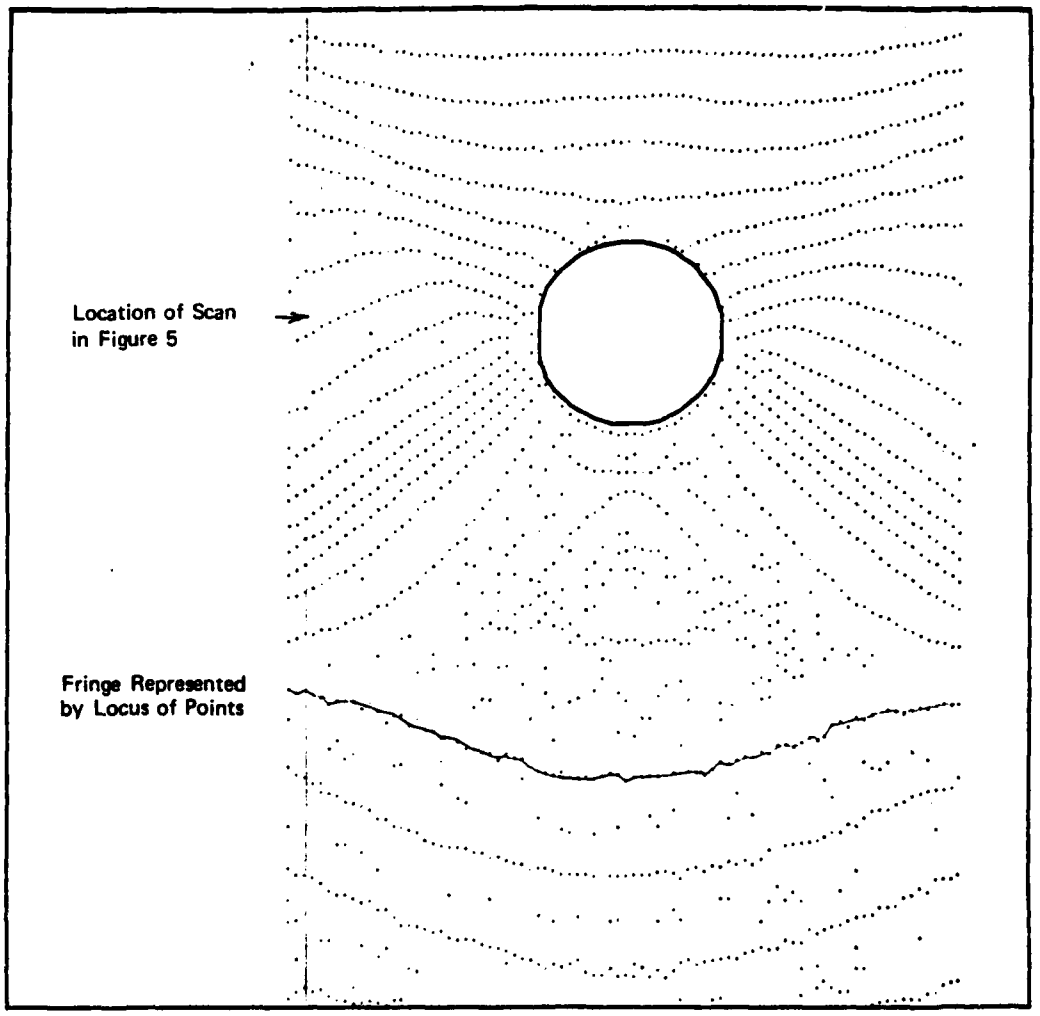

Figure 6. Plot of points which lay on fringe centerlines.

DETERMINATION OF FRINGE CENTERLINES

Having smoothed the data, it is necessary to locate the positions of the centerlines of the Moiré fringes. The light fringes are indicated by the high intensities and the dark by the low intensities.

Each scan of the image is processed individually. Travelling along a scan from top to bottom, the peaks and valleys in the intensity profile are located and their coordinates (in terms of pixels) are recorded in a data file. From this point on, the intensity values are no longer used. The coordinates for the dark fringes are written into one file and those for the light into another. This allows separate processing of the light and dark, or they may be combined for higher resolution.

Figure 6 is a plot of the peaks selected by the computer program from the data of which that in Figure 5 is one scan.

IDENTIFICATION OF MOIRÉ FRINGES

At this point in the process, we have an array of points, each of which lies on the centerline of a Moiré fringe. There are no other relationships which have been established between points.

The task at hand is to group the points into sets which represent fringes. On achieving this, they can be identified by their set numbers and the data can be processed further.

The process of grouping the data into sets is semiautomated. It requires the interactive use of a Tektronix graphics display computer terminal. An outline of the object under study is displayed on the screen along with the data points. Using the terminal's graphic cursor as an input device, individual points can be selected and connected to others through the use of various methods provided by the software. These methods are the selection of individual points, approximation of a straight line through a group of points, or of a parabola through a group of points. The use of linear or parabolic approximations allows for significantly faster point identification than individual selections might provide. This procedure also provides additional filtration of noise not removed by the FFT. Sets of points are identified and grouped in this manner. Upon completion of set identification, they are stored with their assigned set numbers.

The assigned set numbers uniquely identify sets of data of equal fringe order. For various reasons (e.g., a hole in the specimen or a strain reversal), there may exist more than one set which is of the same integral or fractional fringe order. Set numbers are changed to the appropriate fringe orders before processing can be completed.

STRAIN DETERMINATION

The preceding process leaves us with a number of points for which we have the coordinates and the Moiré fringe order. We now wish to smooth these data and determine the strain field.

The method employed herein is due to Tessler and Freese,* which appears to be one of the major contributions of the present effort. It is based on a concept originally introduced in 1968 by Hinton and Irons,[2] but not subsequently followed up (possibly because the lack of automated optical scanning technology at that time may have made application of the approach somewhat inconvenient). The basic idea is to overlay a finite element mesh over the body and, introducing a typical set of interpolation functions for the displacement components, establish a set of node point displacements which correspond to a least square fit to the experimental data obtained from the scanning process. It turns out that establishing the least square fit for each displacement component is closely analogous to generating a stiffness matrix for a problem governed by a second order partial differential equation such as Laplace's equation.

The important advance of the Tessler-Freese* method over the original Hinton and Iron's[2] method is the introduction of elements which are fully conforming, and having derivative continuity appropriate to strain fields in elastic continua. In addition,

*TESSLER, A., and FREESE, C. E., Publication in Preparation.

2. HINTON, E., and IRONS, B. *Least Squares Smoothing of Experimental Data Using Finite Elements.* Strain, v. 4, 1968, p. 24-27.

the present implementation includes an automated mesh generator which makes the allowances for boundary geometries in typical specimens a much simpler process than would otherwise be possible. (This would normally entail a difficult problem involving distinguishing optically between specimen boundaries and fringes that would tend to reduce the possibility of automating the process as much as possible.)

Several important benefits result from the finite element-based smoothing approach. These include:

1. Automatic smoothing of displacements as a result of the least-squares aspect of the fit.

2. Simultaneous inclusion of all data points (such as the set shown in Figure 6) in establishing the displacement field.

3. Convenience provided by the finite element mesh generator in allowing for complicated specimen geometry, such as multiply-connected geometries (i.e., plates with holes).

4. Reduction in the amount of data needed for a given degree of accuracy as opposed to methods based on local smoothing.

5. Provision of a continuous displacement field from the fringe data which would normally require infinitely close fringe orders.

To perform the analysis, it is necessary to generate a finite element mesh made up of triangular elements. This mesh is overlaid on the fringe data, such that each element contains at least one data point (Figure 7).

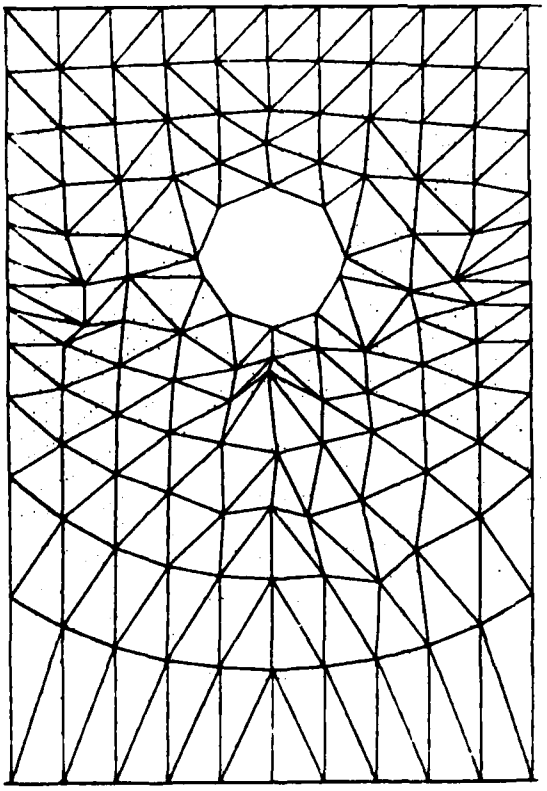

Figure 7. Finite element mesh overlaid on fringe data.

The finite element solution of this problem involves a vector of nodal unknowns in the form $[u_j, \partial u_j/\partial x, \partial u_j/\partial y]$ for i = 1, 2, 3, (nodal numbers) and j = x, y. The smoothed displacements u_j (j = x, y) and displacement gradients $\partial u_j/\partial x$ and $\partial u_j/\partial y$ are continuous functions within each element and across element interfaces.

The shear strains can be determined by superposition of the cross derivatives of the displacement.

Output of the strain analysis can be displayed by means of an in-house contour plotter capable of displaying the entire field. A display of the strain profile along any line can also be obtained. Figure 8 is a typical strain contour plot and Figure 9 is a vertical profile near the edge of the hole.

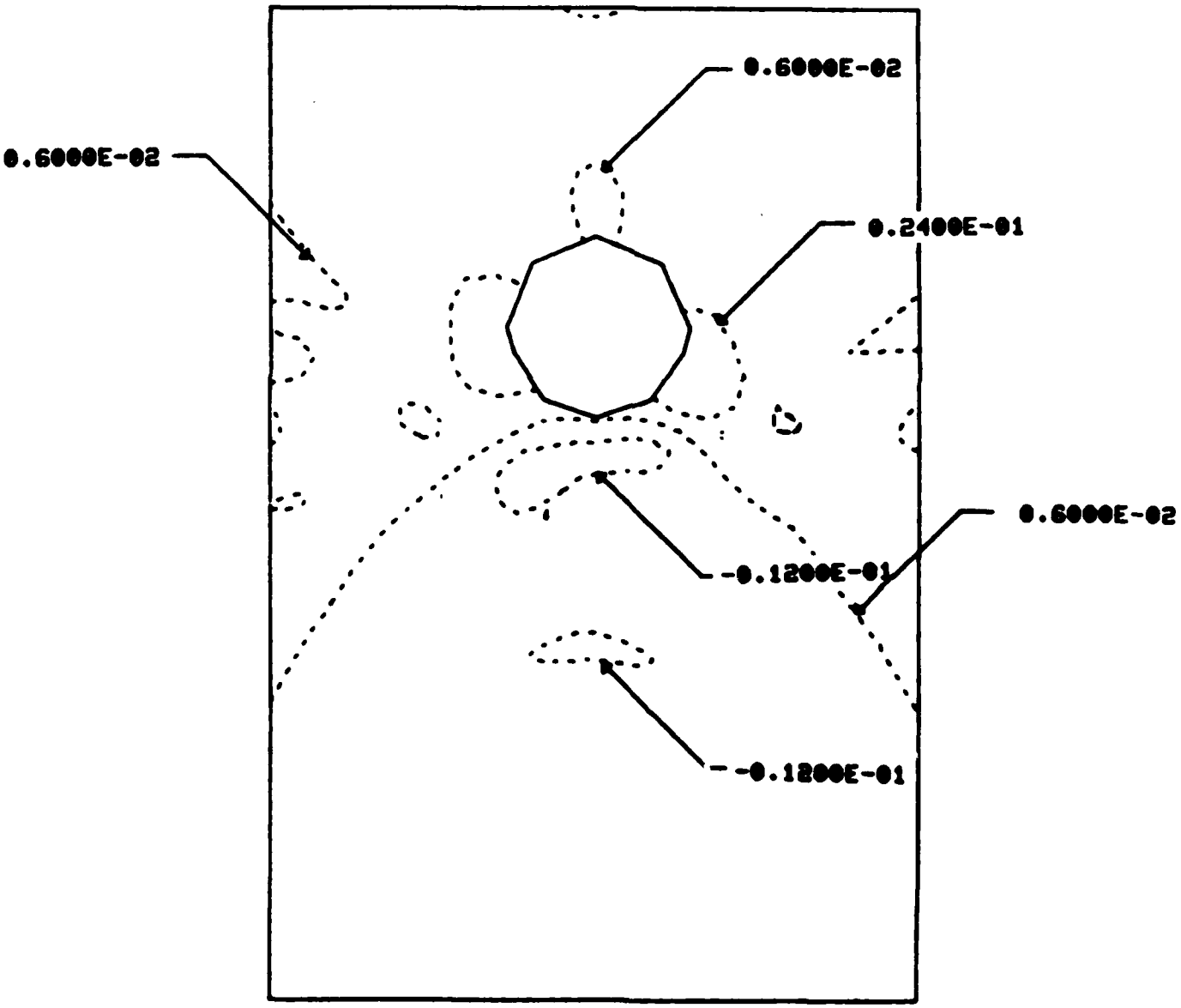

Figure 8. Full field strain contour plot.

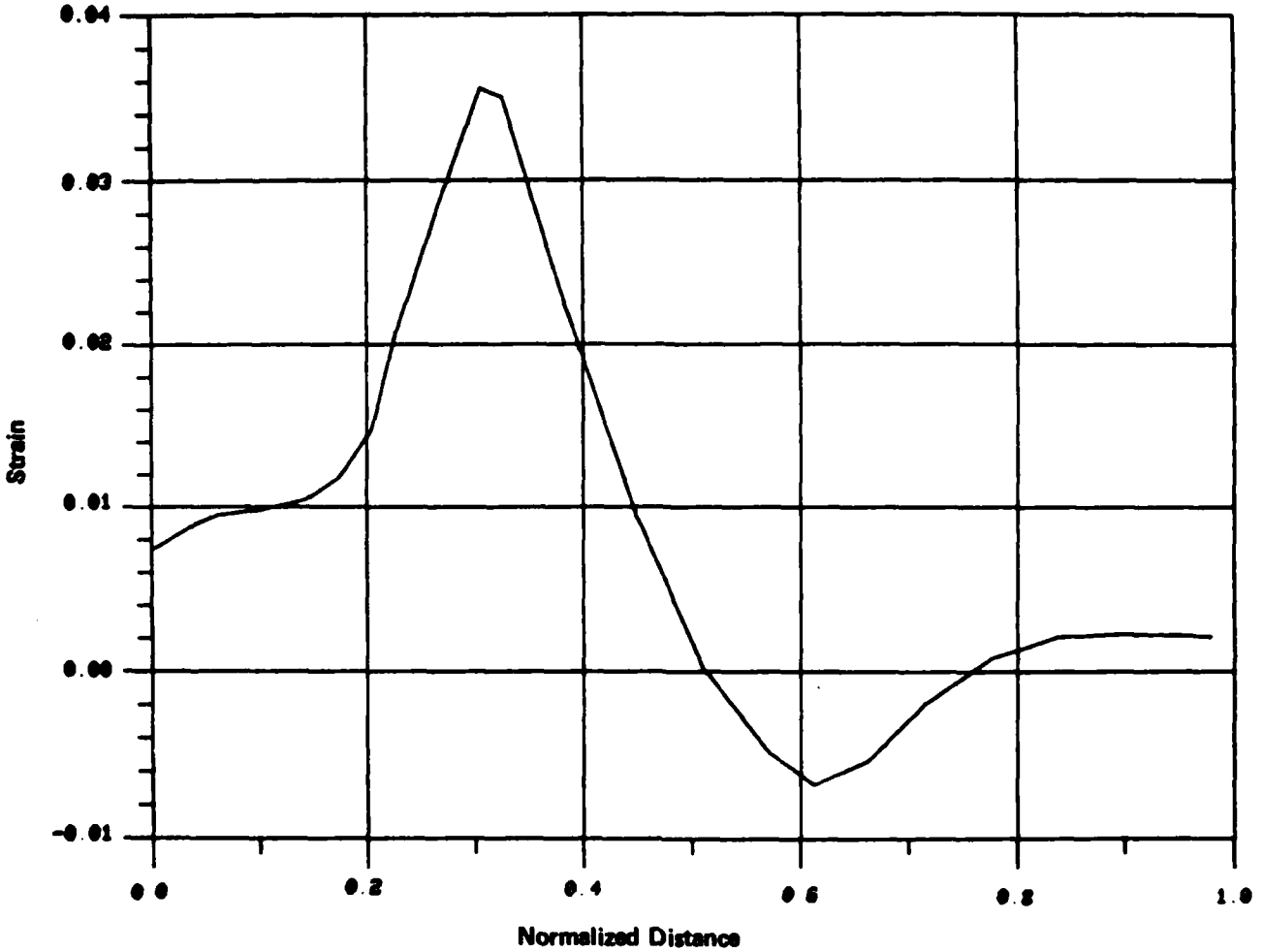

Figure 9. Strain profile along a vertical line near hole edge.

CONCLUSIONS

The process described provides for the semiautomated reduction and analysis of full-field Moiré fringe displacement data. Having full-field data allows a much more complete description of the displacements than would be obtained by manually selecting points to be used in an analysis.

Fourier transform filtering is a very effective tool for removing noise from the data and permits accurate location of the fringe centerlines.

The finite element global smoothing technique is a powerful method for obtaining strain information from known displacements and will find extensive use in future work.

ACKNOWLEDGMENTS

The assistance of Mr. C. E. Freese in the interfacing of his computer codes to this work, and of he and Dr. A. Tessler in the use of their finite element formulation is greatly appreciated, as is the general assistance of Mr. D. Oplinger.

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Key Words

Strain (mechanics)
Finite element analysis
Image processing

A method for analyzing Moiré fringe photographs without acquiring point by point data manually is described. A computer controlled video digitizer is used to acquire video intensity data for up to 1024 x 1024 pixels per photograph. Software was developed to acquire the data and store it locally to the digitizer's computer. Data reduction and analysis is performed on a host minicomputer. Software for this host was developed to upload all the data, perform error checking and subsequently perform the reduction and analysis. The data analysis is performed using a finite element global smoothing technique. This method allows the displacements to be input to the analysis and the strains determined. Results may be plotted as contours of strain or slices may be taken at any location in any direction.

END

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